1. Introduction

Global and urban environmental problems are being caused by a rapid increase in carbon dioxide (CO2) and harmful exhaust emissions due to the burning of fossil fuels. The remaining available oil deposits and the growing cost of conventional fuels for automotive engines have spurred the research for alternative fuels. Alternative fuels such as CNG, HCNG, LPG, LNG, Bio-Diesel, Biogas, Hydrogen, Ethanol, Methanol, Di-Methyl Ether, Producer gas, P-series have been tried worldwide. Though diesel engines have several advantages like high thermal efficiency, torque capacity, low HC and CO emissions, reliability, adaptability and cost effectiveness, but they suffer from high concentration of NOx, smoke and particulate emissions. The stringent emission norms cannot be met through engine design and exhaust after treatment alone [4, 11].

Di-methyl ether (DME) is one such fuel that has been attracting notable attention of researchers as a clean alternative fuel for diesel engines without large sacrifice in vehicle performance. Di-methyl ether (DME) is the simplest ether, consisting of two methyl groups bonded to a central oxygen atom, as expressed by its chemical formula CH_3OCH_3. It has a low carbon-to-hydrogen ratio (C:H) [12]. With the chemical structure somewhat similar to methanol, DME contains oxygen and no carbon-carbon bonds, thus limiting the possibility of forming carbonaceous particulate emissions during combustion. The DME have some significant properties such as Cetane number, boiling point, auto ignition temperature and some properties of concerns are viscosity, heating value and vapour pressure [39].

Cetane number of fuel is a measure of the fuel's ability to auto-ignite, has an important influence on diesel combustion and is a meaningful indicator of a fuel's value for diesel engines. Fuels with a high Cetane number will ignite quicker and thus will have a short ignition delay. This lowers premixed burning of the fuel, which in turn lowers NOx and noise emissions. DME has a higher Cetane number (55-60) than Diesel Fuel and thus it will ignite readily and burn more completely with relatively short ignition delay. Low boiling point leads to easier starting of engine during cold weather conditions. Due to low boiling point DME vaporizes easily in the cylinder, when a liquid-phase DME spray is injected into the engine cylinder yielding better atomization and hence improving combustion [16].

The viscosity of DME is about 10% of diesel fuel and is extremely low compared to most other fuels. Diesel fuel has a kinematic viscosity at 20^0 C of 2.5-3.0 as compared to Methanol 0.75, Gasoline 0.6 and Dimethyl ether of 0.25. Low viscosity of DME is an advantage for DME as a fuel

as it will reduce the effort in delivering the fuel supply into the engine cylinder during cold weather conditions. But it has a disadvantage as it causes the leakage from the fuel supply system which relies on small clearances for sealing [2]. Its lower lubricity characteristics can cause intensified surface wear of moving parts within the fuel-injection system which requires attention [3].

DME is a colorless gas at room temperature with an ethereal odor, a vapor pressure of 530 kPa at 298 K and is highly flammable in air (3.4-18%). The vapor pressure of DME is comparable to LPG, and DME liquefies easily at relatively low pressurization. DME in a gaseous state is invisible under standard atmospheric conditions (0.1 MPa at 298 K). When it is pressurized above 0.5 MPa, it condenses to the liquid phase. So, it can be easily handled and stored as liquefied gas, in the form of a colorless clear liquid, similar to LPG. Due to low vapor pressure, pressurized fuel system is required which increases the overall cost of the DME engine [5]. Gaseous DME is denser than air while liquid DME has a density two thirds that of water. Due to the lower enthalpy of combustion and lower density of DME than the diesel fuel, the volumetric flow rate of DME required is 1.85 times more than the diesel fuel in order to produce the same amount of input energy [31].

Modulus of elasticity of DME is lower than that of diesel fuel, with the difference being greatest at lower pressures. Thus, the compressibility of DME is usually four to six times higher than that of diesel in a closed system and the compression work of the fuel pump for DME is greater than it is for diesel fuel by up to 10% in an open system [22]. It dissolves in water up to 6% by mass. However, it is not compatible with most elastomers including those used in conventional diesel fuel system due to its corrosiveness, so that careful selection of materials is necessary to prevent deterioration of seals after prolonged exposure to DME [12]. The sealing of DME filled vessels, for example, can be achieved with inert material, such as polytetrafluoroethylene (PTFE). DME is non-toxic and environmentally benign. At low mole fractions (a few percent by volume) the gas has hardly any odour and causes no negative health effects. Even at high mole fractions (>10% by volume) there is no effect on human health except narcotic effects after long exposure and it may be recognized by the odour. DME displays a visible blue flame when burning over a wide range of air–fuel ratios, similar to natural gas, which is an important safety characteristic. Nevertheless, the operation of DME combustion system needs the adoption of rigorous procedures for safe operation due to the wide flammability limits [6].

DME is a synthetic fuel produced by the conversion of various feed stocks such as natural gas, coal, oil residues and bio-mass. DME, most commonly produced from natural gas, provides a possible avenue for the utilization of various natural gas reserves that are inaccessible by pipelines.

2. Literature Review

Air pollution, global warming, acid rain, smog, odours are a serious problems especially in large cities. Many types of combustion contribute to this problem. Automotive vehicles have been identified as a significant source of carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen (NOx) and particulate matter (PM). Keeping in view the Eco-mobility, emission standards are constantly being changed in an attempt to lower exhaust emissions. Stringent emission legislations such as Euro 5 emission norms for diesel fueled passengers car, from the year 2009, propose limits of NOx emissions 0.18 g/km, HC+NOx 0.23 g/km, PM 0.005 g/km and CO 0.5 g/km. In future, Euro 6 emission norms, from the year 2014, propose limits of NOx emissions about 0.08 g/km, HC+NOx 0.17 g/km, PM 0.005 g/km and CO 0.5 g/km.

These stringent emission norms cannot be met through engine design or control parameters alone. The various methods like retarding the injection timing, use of high injection pressure, EGR, catalytic converters, split injection and modifying the combustion chamber geometry to enhance the swirl and squish are being tried to reduce emissions but problems are still prevailing in the operation of these techniques. Meeting such emission standards will be more difficult for diesel engines by the use of conventional fuel such as diesel and biodiesel as a neat fuel. In an attempt to meet such standards the various alternative fuels such as Methanol, Ethanol, Natural gas dual fuel, Biodiesel etc. have been tried in CI engines worldwide.

However, to overcome these problems and to meet such stringent emission norms DME is regarded as an excellent alternative fuel for CI engines. Recent studies and literature survey also show that by using DME in CI engines the Eco-mobility with ultra-low exhaust emissions can be demonstrated with totally smoke free operation.

The detailed review of relevant patents and research papers is carried out to demonstrate the technical feasibility of DME-diesel blended fuel in CI engine and use of proper techniques to improve performance and emission characteristics. The literature review is classified into five groups viz. Patents, Experimental methods (Neat DME), Experimental methods (DME/diesel blend), Computational methods and DME production.

2.1 Chronological account

In the year 1995, the first conceptual study of DME as an alternative fuel for CI engine was proposed by Kapus and Cartellieri. McCandless and James received the United States Patents of

Dimethyl ether powered engine in 1996 and Fuel injection system for clean low viscosity fuels in 1998.

In the later 90's various researchers worked on conceptual design of DME engine related to fuel storage, fuel supply system and fuel injection system with spray characteristics of DME and its effect on ignition delay. In 1998 Kajitani S et al. investigated on direct injection diesel engine operated with propane – DME blended fuel.

Many researches were conducted in the decade from 2000 to 2010 wherein in 2001; McCandless and James received a United State patent for internal combustion engine with low viscosity fuel system. Kajitani S et al. in 2002 studied the effect of low compression- ratio di-methyl ether diesel engines. In 2004, Jun Song et al. experimentally investigated the performance of a controllable premixed combustion engine fueled with dimethyl ether. Wang Ying et al. in the year 2006 investigated on diesel emission improvements by the use of oxygenated DME/diesel blend fuels and also in 2008 used experimental method to study the application of DME/diesel blends in a diesel engine. Wang Ying et al. in 2008 experimentally studied the exhaust emissions from a multi-cylinder DME engine operating with EGR and oxidation catalyst.

In 2009, Brusstar et al. have applied for United States Patent on Low emission dimethyl ether (DME) engine. Xu Lijun et al. in 2010 investigated on simulation of Diesel/DME Mixed Injection System. Also in 2010 Su Han Park et al. used simulation method to study the effects of dimethyl-ether (DME) spray behavior in the cylinder on the combustion and exhaust emissions characteristics of a high speed diesel engine. Further in 2011, Mo Youn et al. investigated on the fuel spray and emission reduction characteristics for dimethyl ether (DME) fueled multi-cylinder diesel engine with common-rail injection system.

2.2 Remarks from literature reviewed and need for the present work

A comprehensive literature review is undertaken to understand the technical feasibility and the effect of DME-diesel blend and neat DME on the performance and emission characteristics of CI engine. The remarks from latest literature are as follows:

1. Several new concepts such as low compression ratio DI diesel engines, diesel fuel blended with DME, common rail direct injection (CRDI) and homogeneous charge compression ignition (HCCI) engines have been investigated to improve engine performance and exhaust emissions characteristics by using DME as an alternative fuel.

2. The low viscosity of DME regarded as a weakness because it would cause the dysfunction of a conventional film bearing between the needle and sleeve of the injector, and result in leakage and wear.
3. The higher fuel volume required relative to diesel fuel in order to overcome the DME's disadvantages of the lower calorific value and density.
4. The low boiling point of DME would also demand a pressurized system to maintain the liquid state of the fuel. Corresponding high pressure on the back of the needle would decrease the injection rate and consequently hamper the engine performance.
5. It shows that the technology with pure DME as an alternative fuel for CI engine and vehicle has a relatively long route.
6. Practically, the addition of some oxygenated DME to diesels to reduce engine emissions without engine modification seems to be a more attractive proposition. Thus, the relative "goodness" of each fuel might be utilized if the diesel and DME fuels are blended. The fact that DME and diesel blend well with each other without any solvent encourages the investigation of properties of the mixture in different proportions, as potential fuels for diesel engines. The properties of DME-diesel blend is given in Table 2.1
7. The addition of DME to diesel fuel changes the physicochemical properties of fuels. With an increase of DME mass fraction, density, kinematic viscosity, low calorific value and aromatic fractions of the blends decrease. Simultaneously, cetane number, C/H ratio and oxygen content of the blends are enhanced, which has some effects on the ignition and combustion of the blends.
8. Physical and chemical properties of DME and diesel display mutual solubility at any ratio.
9. The vapor pressure of DME/diesel blends is lower than that of pure DME at the same temperatures and it increases with an increase of DME mass fraction in blends. However, the increasing magnitude of vapor pressure for blends is lower than that for pure DME. It is well known that vapor lock easily occurs in the pure DME fuel system and some pressure must be supplied to keep fuel in the liquid state. Now, due to a lower vapor pressure for blend fuels, the lower fuel supply pressure can keep blends in the liquid state. This lower fuel supply pressure is beneficial for the fuel transportation and storage safety.
10. By taking relative advantages of DME and diesel, the DME/diesel blends could achieve satisfactory properties in lubricity and atomization, which contributed to improvements in spray and combustion characteristics.
11. Fuel spray has an important influence on the combustion and emission of CI engines. It is evidently shown that an addition of DME could lead to decreased spray penetration but

increased spray angle. It can be attributed to two facts. First, the density of blend is lower than that of diesel and the volatility of blend is higher than that of diesel fuel. Second, the compressibility of DME/diesel blend fuel enlarges owing to the addition of DME into diesel, which means a lower fuel supply pressure and injection pressure can be used for blended fuel.

12. It can be seen that the DME addition supplies an amount of oxygen for fuel blends, so it would have an influence on engine's combustion and emissions. The fuel properties show that DME has a higher oxygen content and cetane number, compared to those of diesel fuel. DME has only C–H and C–O bonds, no C–C bond, therefore, the emissions produced from combustion such as smoke and PM are expected to be lower than diesel operation.
13. The energy consumption reduces by adding a low fraction DME into diesel. These can be explained by the fact that there is 34.8% oxygen in DME molecule and it makes DME's combustion have an ability of oxygen supply by itself. In addition, DME has a better atomization. All these factors are helpful for improving the engine's combustion. However, with an increase of DME mass fraction in blend fuel, the fuel supply duration and late combustion phase extends, which finally leads to an increase of energy consumption. As a result, BSEC of high fraction DME blend is a little higher than that for low fraction DME operation and comparable to that of pure.
14. The more DME mass fraction in blend is, the lower the power output is. The reasons are possible that the lower calorific value and the smaller fuel delivery amount resulted from lower density for blend fuels. Lower power output of DME/diesel blend fuelled engine can be improved by enlarging the fuel supply amount of pump per cycle.
15. The amount of heat release of diesel/DME blend fuels during the premixed combustion stage is smaller than that of diesel fuel. The smaller amount of heat release during the premixed combustion stage reduces the combustion pressure and temperature and leads to low NOx emission. The higher the DME content in blends is, the smaller heat release rate is during the premixed combustion stage. This is due to the good auto-ignition and atomization characteristics of the DME in the diesel/DME blends, which improve the combustion process on CI engines.
16. DME/ diesel blend reduces the smoke density significantly, especially at higher loads. It is that an oxygenate additive DME is effectively introduced to the fuel regions and suppress soot formation in the combustion chamber. High oxygen content of the blend fuels combined with low C/H ratio and aromatics fractions are also assumed to contribute to the reduction of smoke at high loads. While, at low and medium loads, diesel fuel burns completely owing to a large air fuel ratio, thus, smoke emission of diesel engine is low and comparable.

17. The NOx emissions are also reduced somewhat in comparison to the engine fueled with neat diesel fuel. DME has a higher cetane number value and an excellent autoignition characteristic, so the ignition delay is shorter and the amount of premixed combustion is smaller than diesel fuel, which makes the maximum in-cylinder pressure and temperature lower and prohibits the formation of NOx. On the other hand, the real injection timing of diesel/DME blend fuels is delayed due to their lower modulus of elasticity, which can reduce the NOx emissions effectively. It is believed that through further modification of injection timing, NOx emissions can be effectively reduced.
18. No significant varying trend in HC and CO emission could be observed and they are higher than those in diesel engines. They pointed to a need to optimize the injection characteristics of the fuel blend and to the need to add an oxidation catalyst to a vehicle fueled in this manner.
19. It is observed that the real burning time advances due to the better atomization and the shortening of ignition delay for blend fuel engines. So, the increased power output and reduced NOx emission can be achieved by retarding the fuel supply advance angle appropriately in the blend fuel engines. Of course, if the fuel supply advance angle is retarded too much, combustion would outspread to an expansion cycle. It finally results in the reduced power output, the increased fuel consumption and the higher exhaust temperature.
20. This is an important step in not only showing that the blend fuel does perform well in an engine with minor modifications to the fuel system, but also showing that DME can give the significant results in lowering smoke emissions of diesel engines.

2.3 Thrust of the present work

Numerous investigations have revealed that DME is a very promising alternative fuel for compression-ignition engines, capable of providing high thermal efficiency, low combustion noise, low NOx levels and soot-free combustion. Recent studies suggest that further comprehensive investigation is required for DME as an alternative fuel for CI engines especially for fuel storage, fuel supply and injection system to overcome high internal leakage problems, to keep DME in liquid state and high volume flow rate requirement.

In the global scenario, fewer efforts by researchers are observed in the use of DME-diesel blend fuel in CI engine. The conceptual study on the performance and emissions of the diesel/DME blends with 10%, 20% and 30% DME by mass is conducted in a CI engine. Till date, no detail study has been carried out in the world on blending of DME/diesel fuel above 30% blending ratio. The

computational study with one dimensional model of DME/diesel blend is carried out but the computational investigation with two/three dimensional model of DME/diesel blend and its validation with experimental results is not yet published on international level.

In India, so far, no research has been reported on neat DME and DME-diesel blend as an alternative fuel for CI engine. This situation demands a comprehensive investigation with computational and experimental methods for the optimization of blending ratio of DME-diesel fuel in CI engine to improve combustion and emission characteristics of CI engine. The effect of DME addition on diesel fuel properties has also not been investigated, which needs more attention. This situation demands a comprehensive investigation on the DME and DME-diesel blend as an alternative fuel for diesel engine.

2.4 Research gaps for the present research

A look at the literature discussed illustrates some gaps among the research work regarding utilization of neat DME and DME-diesel blended fuel in compression ignition engine.

1. A comprehensive investigation is required for fuel storage, fuel supply and injection system for use with DME in CI engine to overcome high internal leakage, to keep DME in liquid state and high volume flow rate.
2. Further investigations are needed to obtain simultaneous reduction of NOx and smoke emissions by utilization of DME in CI engine.
3. Less attention has been paid to the DME-diesel blended fuel use in CI engine.
4. An elaborate investigation about blending of DME to diesel to improve combustion and emission characteristics of diesel is required.
5. Further investigations are needed for the optimization of blending ratio of DME-diesel fuel in CI engine.
6. Optimal injection timing for DME blends with diesel has not been investigated for various blending ratios for different engine loads and its effect on combustion and emission characteristics of CI engine.
7. Effect of DME addition on diesel fuel has not been investigated.
8. Less study related to computational investigation and validation of DME-diesel blend is carried out. Further investigations are required to optimise the blending ratio, injection timing computationally.

3. Statement of Problem

The literature review reveals the importance of the DME fuel in compression ignition engines for the automotives and very few studies of the various aspects of the neat DME and blending of DME with diesel fuel are carried out. Hence, there is a great motivation to utilise DME fuel in CI engine to meet stringent emission norms.

Emission performance of DME fuel will be evaluated for various engine and emission parameters in order to develop a viable technology for diesel engine. Accordingly, methodology will be devised computationally and experimentally for the evaluation of DME and Diesel blend. The proposed title of the research project is **"Investigation on the Performance and Emission Characteristics of a DME-Diesel blended CI Engine"**

Numerous investigations have revealed that DME is a very promising alternative fuel for compression-ignition engines, capable of providing high thermal efficiency, low combustion noise, low NOx levels and soot-free combustion. Recent studies suggest that further comprehensive investigation is required for DME as an alternative fuel for CI engines especially for fuel storage, fuel supply and injection system to overcome high internal leakage problems, to keep DME in liquid state and high volume flow rate requirement.

Practically, the addition of some oxygenated DME to diesels to reduce engine emissions with minor engine modification seems to be a more attractive proposition. Thus, the relative "goodness" of each fuel might be utilized if the diesel and DME fuels are blended.

4. Objectives

The prime objectives of the proposed research work are as follows:

1. To investigate the performance and exhaust emission characteristics of a diesel engine by blending dimethyl ether (DME) to diesel fuel with different ratios.
2. To find the optimized blending ratio of DME-diesel fuel based on performance and emission characteristics.
3. To investigate the effect of different injection timings and to optimize it for the optimally selected DME-diesel blends.

5. Issues

The issues anticipated during proposed work are as follows:

1. Availability of relevant data

The data available on this subject is very inadequate as very few studies are carried out internationally on DME-diesel blended fuel as an alternative fuel for CI engine. The availability of data which gives a good direction and enumerates the required road map is absent here.

2. Availability of DME fuel

Dimethyl ether (DME) fuel is not available in India; hence it should be imported from China or any other country. This activity is time consuming and hence may be regarded as a major issue for the proposed research work.

3. Availability of modified parts & components

Development and modifications of required parts and systems is major challenge in this research work, which includes fuel storage system, fuel supply system, fuel injection pump, fuel return line, etc. This may be another major issue for the proposed work.

4. Development of blending method

Proper method of blending DME to diesel fuel is not available which needs to be developed for this research work.

5. Safety approval

The safety approval for each blend of DME-diesel fuel from Petroleum Explosive Safety Organization (PESO), Govt. of India will be required.

6. Funds

The DME fuel and other components are to be imported from overseas vendors. The fuel storage, fuel supply, fuel return line and F.I. pump parts are to be specially developed, modified or imported for the respective engine. These activities are time consuming and very expensive.

6. Methodology

The main purpose of this investigation is to find out the feasibility of DME-diesel blended fuel by different strategies to improve performance and emissions of diesel engine. Emission

performance of DME-diesel fuel will be evaluated for various engine and emission parameters in order to develop a viable technology for diesel engine. Accordingly, methodology will be devised computationally and experimentally for the evaluation of DME-diesel blend in diesel engine. The proposed research work involves different activities to ease out the process. By keeping in view the objectives of the study the scope of this work is categorized into five phases.

- ☐ **Phase 1:** Literature review & data collection
- ☐ **Phase 2:** Engine modelling and Simulation
- ☐ **Phase 3:** Parts development, modifications and proto engine building
- ☐ **Phase 4:** Blending of DME with diesel fuel
- ☐ **Phase 5:** Experimental and computational tests, Validation and Engine optimisation
- ☐ **Phase 6:** Results analysis & reporting

6.1 DME-diesel blend fuel

Different kinds of DME-diesel blend fuels will be used for the research work. Five types of blended fuels such as DIME 5, DIME 10, DIME 20, DIME 30 and DIME 35 will be used for the study. In our research the blend of 5% DME and 95% diesel by mass will be called DIME 5; the blend of 10% DME and 90% diesel by mass will be called DIME 10; accordingly the blend of 20% DME and 80% diesel by mass will be called DIME 20; the blend of 30% DME and 70% diesel by mass will be called DIME 30 and the blend of 35% DME and 75% diesel by mass will be called DIME 35. The experimental work will be carried out at ARAI/MMCOE, Pune.

6.2 Baseline Engine

In this investigation a four stroke, four/six cylinder, direct injection/CRDI, water-cooled, naturally aspirated/turbocharged diesel engine will be used in the study.

6.3 Modifications

In view of objectives of the study the baseline engine with no modifications in the structure will be used. Some modifications in fuel storage system, fuel supply system, fuel return system and fuel injection system will be made, which are as follows:

- ☐ The diesel fuel tank will be replaced by LPG vessel to prevent DME from evaporation. The fuel outlet will be at the bottom of the vessel and the inlet of the returned blend fuel from engine will be at the top.
- ☐ The fuel supply line will be pressurized to avoid evaporation of DME at ambient conditions. The DME/diesel blend fuel supply line will be pressurized about 7 bar by an electrical pump.
- ☐ The fuel return line will be insulated and pressurized to prevent DME from evaporation when the surplus blend fuel from fuel injector and fuel injection pump is returning to the fuel storage tank.
- ☐ Necessary modifications will be made in the fuel injection pump to increase the volumetric flow rate of fuel and to adjust the variable injection timing.
- ☐ The existing rubber fuel pipe will be replaced by the copper pipe due to the causticity of DME to rubber pipe.

6.4 Computational method

In this research work for the computational method the computational fluid dynamics (CFD) softwares will be used. First, the computational model of the baseline diesel engine will be developed. The experimental test by using neat diesel will be carried out and then the computational test by CFD software with same condition with neat diesel will be carried out and these results will be compared with the experimental results to validate the computational model. The validated computational model will be used to test predetermined blending ratios of DME-diesel fuel for various engine parameters to get better engine performance.

6.5 Experimental method

The experimental tests with same parameters and similar conditions of computational study will be carried out and these results will be validated with the computational results. Based on the computational and experimental results of the various kinds of fuel blends the optimized blending ratio of DME-diesel fuel will be investigated from better engine performance. The optimized DME-diesel blended fuel will be used for further research. The experimental tests at variable injection timing, variable load and variable engine speed by using optimized DME-diesel fuel will be carried out for different engine and emission parameters to get better results. The optimized injection timing at different brake load conditions will be investigated to get better results.

6.6 Performance parameters

The evaluation of engine tests needs to measure the corresponding parameters. In overall, the parameters can be divided into two main categories as following:

A) Engine performance parameters

The main performance parameters desired from the engine are as follows:

i) Brake power, BMEP, Torque

ii) Fuel consumption

iii) Brake specific fuel consumption (BSFC)

iv) Brake thermal efficiency (BTE)

v) Air consumption

vii) Fuel-Air ratio, Equivalence ratio (φ)

vi) Engine speed

vii) Exhaust gas temperature

B) Exhaust emission parameters

In this investigation the exhaust emission analysis will be done for exhaust smoke, particulate matter (PM), unburned hydrocarbon (UBHC), carbon monoxide (CO), carbon dioxide (CO_2) and oxides of nitrogen (NOx).

7. Tools and Techniques

ARAI is well equipped with latest state of the art equipments to carry out the engine performance and emission related activities. Typically following set of equipments will be required (but not limited) to carry out the engine experimental work.

1. Steady State Engine Dynamometer
2. Engine Dyno controller & Data Acquisition system
3. Fuel Consumption meter
4. Throttle Motor
5. Fuel Conditioning system
6. Engine cooling system
7. Raw Emission test bench
8. Particulate Matter measurement system.
9. Conditioning Air system
10. Smoke Meter

11. Engine exhaust system

12. Set of Pressure, Temperature & humidity Sensors.

8. Research Plan (time schedule)

Research work plan for the proposed objectives is presented as follows:

Sr No	Activity	2011	2012				2013				2014			
		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Course Work													
2	Literature review													
3	CFD Simulation-Engine Modeling													
4	Computational Testing													
5	Experimental Set up													
6	Experimental Testing													
7	Data Analysis													
8	Synopsis Preparation													
9	Thesis writing													
10	Project reviews													

Q1: January - March; **Q2:** April - June; **Q3:** July - September; **Q4:** October - December

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Research Proposal Approval

The revised research proposal titled **"Investigation on the Performance and Emission Characteristics of a DME-Diesel blended CI Engine"** of Mr. Krishnarao R. Patil (SIRI Ph.D. ID: 100030) is prepared under my supervision and approved for further research work.

Place: Pune

Date: 15/06/2012

(Dr. S. S. Thipse)

Guide

Sr. Assistant Director,